Day 1: Introduction to Machine Learning

ARISE 2020: ECE Machine Learning Lab

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Outline

1 Introductions

2 What is Machine Learning?

3 Course Outline

4 Setting Up Python

5 Problem Solving as an Engineer

6 Basics of Programming in Python

7 Matrices and Vectors

8 Visualizing Data

9 Lab: Plotting Functions

10 ML vs. AI, Why the Hype Today?

11 Supervised Learning

Tell us about yourself

- Write down the following pieces of information in your book:
  - Name
  - Grade
  - Where are you from?
  - What time did you wake up this morning (exact times please!)?
  - What is your favorite thing to do during Quarantine?
  - What do you want to get out of this class?
  - One rule you'd like to propose for the classroom
- Discuss what you've written down
- We'll visualize this data in python later today
  - Link to excel sheet here

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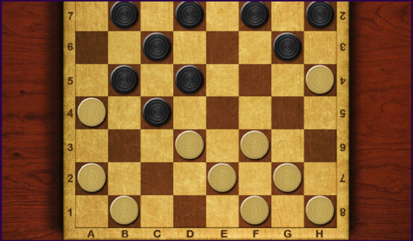
Machine Learning

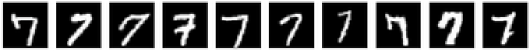
- Most recent exciting technology
- We use these algorithms dozens of times a day
  - Web search engine
  - Face detection
- Machine Learning is an important component to achieve the big AI dream
- Practice and critical thinking are the key to learn machine learning

Definition

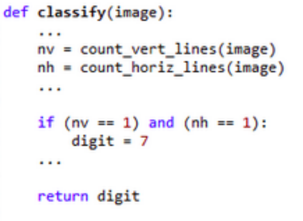
- Machine Learning is a field of study that gives computers the ability to learn without being explicitly programmed.



Example: Digit Recognition



- Challenges with expert approach
  - Simple expert rule breaks down in practice
  - Difficult to translate our knowledge into code
- Machine Learning approach
  - Learned systems do very well on image recognition problems



```
def classify(image):
    ...
    nv = count_vert_lines(image)
    nh = count_horiz_lines(image)
    ...

    if (nv == 1) and (nh == 1):
        digit = 7
    ...

    return digit
```

Machine Learning Problem Pipeline

1. Gather data
2. Visualize the data
3. Formulate ML problem
   - Regression vs Classification
   - Choose an appropriate cost function
4. Design the model and train to find the optimal parameters of the model
   - Prepare a design matrix
   - Perform feature engineering
   - Validate your choice of hyper-parameters using a cross-validation set
5. Evaluate the model on a test set
   - If the performance is not satisfactory, go back to step 4

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Course Outline

- What is Machine Learning and why is it so relevant today?
- Linear Regression
- Logistic Regression
- Back propagation algorithm
- Mini-Project on topics covered so far
- Neural Networks
- Conv Nets
- PyTorch tutorial
- Applications of CNN's and RNNs
- Self-Driving Cars Final Project

Course Format, Website, Resources

- Course Website: `github.com/ApoorvaNandini/ARISE2020`
  - Github: share collections of documents, repositories of code
  - Contains lecture slides, code notebooks, and datasets
  - Slides posted before lecture, demo code and solutions posted after
- Strongly encourage programming in Python via Google Colab
  - No installation required
- Will give additional resources based on student interest

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Setting Up Python

- Scripting Python
  - Sequentially execute lines of code
- Jupyter Notebook
  - Code Blocks and Text Blocks (markdown)
  - Variables saved in workspace (across code blocks)
- Google Colab
  - Jupyter Notebook online (no real-time collaboration)
  - No installation
  - Free GPU for 12 hours
- Set up 1 of these 3 things and `print(’hello world!’)`

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Black-Box Abstraction

[¡+-¿]

- Can deal with many things with only knowing their **inputs** and **outputs**
- Need not know the details of the insides of our “boxes”
- Examples:
  - MTA turnstile
  - Python’s `print()` function
  - Your Smart-Phone
  - Others?
- When does Black-Box Abstraction fail?

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Python Basics

- Program
  - We write operations to be executed on variables
- Variables
  - Referencing and interacting with items in the program
- If-Statements
  - Conditionally execute lines of code
- Functions
  - Reuse lines of code at any time

Python Basics

- Lists
  - Store an ordered collection of data
- Loops
  - Conditionally re-execute code
- Strings
  - Words and sentences are treated as lists of characters
- Classes (advanced)
  - Making your own data-type. Functions and variables made to be associated with it too.

Modules/Libraries/Packages

- NumPy: math, vectors and matrices
- MatPlotLib: plotting graphs, visualizing data
- Pandas: convenient for storing and retrieving data
- Sklearn: convenient wrapper for simple ML problems
- TensorFlow: computational graph, neural networks
- Keras: convenient wrapper for TF
- PyTorch: deep learning framework, used mostly by Research community

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Vectors

- A **vector** is an n-tuple of numbers or symbols
  - Ex: integer 4-tuple: $\mathbf{v} = (1, 5, 2, 9)$
- Vectors of the same size may be added together, element-wise
  - Ex: $\mathbf{u} = (3, 6, 0, -5)$
    $\mathbf{v} + \mathbf{u} = (1 + 3, 5 + 6, 2 + 0, 9 + (-5)) = (4, 11, 2, 4)$
- Vectors may be scaled by a number, element-wise
  - Ex: $3\mathbf{v} = (3 \times 1, 3 \times 5, 3 \times 2, 3 \times 9) = (3, 15, 6, 27)$
- **Dot-Product**: sum of element-wise products of two vectors
  - Ex:
    $\mathbf{u} \cdot \mathbf{v} = 3 \times 1 + 6 \times 5 + 0 \times 2 + (-5) \times 9 = 3 + 30 - 45 = -12$
- Length of a Vector (L2 Norm) : $||\mathbf{x}|| = \sqrt{\mathbf{x} \cdot \mathbf{x}}$
  - Ex: $||\mathbf{v}|| = \sqrt{1 + 25 + 4 + 81} = \sqrt{111}$
- Dimension of a vector
  - Ex: $\mathbf{u} = (3, 6, 0, -5)$; $\dim(u) = 4$

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Matrices

- A **matrix** is a rectangular array of numbers or symbols arranged in rows and columns
  - Ex: 2 by 3 matrix, $M = \begin{bmatrix} 1 & 9 & -12 \\ 15 & -2 & 0 \end{bmatrix}$
- Matrices of the same shape may be added together, element-wise
  - Ex: $A = \begin{bmatrix} 1 & 1 \\ 2 & 1 \end{bmatrix}, B = \begin{bmatrix} 0 & 8 \\ 7 & 11 \end{bmatrix}, A + B = \begin{bmatrix} 1 & 9 \\ 9 & 12 \end{bmatrix}$
- Matrices may be scaled, element-wise
  - Ex: $aB = \begin{bmatrix} 0 & 8a \\ 7a & 11a \end{bmatrix}$, where a is a scalar

More About Matrices

- Matrices may be multiplied together provided their shapes meet the criteria
  - $(C)_{ij} = c_{ij} = \sum_{k=1}^{N} a_{ik} b_{kj}$
  - Criteria: for AB to be valid, # cols of A must equal the # rows of B
  - Result is a matrix with shape (# rows A, # cols B)
  - Ex: A is (2 x 3) and B is (3 x 5), $C = AB$ is (2 x 5)
  - Example on board
- **Transpose**: A^T swaps the rows and columns of matrix A
- **Inverse**: A^{-1} satisfies the equation $AA^{-1} = A^{-1}A = \mathbb{I}$
  - Square matrices only!

Vectors and Matrices

- We may consider a vector as a matrix
  - **Row Vector**: shape (1 x N)
    Ex: $\mathbf{v} = \begin{bmatrix} 1 & 5 & 2 & 9 \end{bmatrix}$
  - **Column Vector**: shape (N x 1)
    Ex: $\mathbf{v} = \begin{bmatrix} 1 \\ 5 \\ 2 \\ 9 \end{bmatrix} = \begin{bmatrix} 1 & 5 & 2 & 9 \end{bmatrix}^T$
  - We'll consider vectors as column vectors by default
- Vector-Matrix Multiplication: on board
  - In what "dimension" is our vector starting, and where is it going to?
- Dot Product:

Vectors and Matrices

- We may consider a vector as a matrix
  - **Row Vector**: shape (1 x N)
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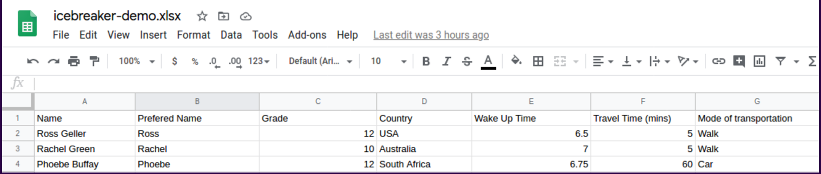
Looking at our ice-breaker data in spreadsheets

- Columns have labels in the first row
- Collected data (numbers, words) follow below
- Let's export it to a Comma-Separated Values (CSV) file and open it


icebreaker-demo.xlsx
File Edit View Insert Format Data Tools Add-ons Help Last edit was 3 hours ago
100% $ % .0 .00 123 Default (Ari... 10 B I S A
fx

	A	B	C	D	E	F	G
1	Name	Prefered Name	Grade	Country	Wake Up Time	Travel Time (mins)	Mode of transportation
2	Ross Geller	Ross	12	USA	6.5	5	Walk
3	Rachel Green	Rachel	10	Australia	7	5	Walk
4	Phoebe Buffay	Phoebe	12	South Africa	6.75	60	Car

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Lab: Plotting Functions

- Generate and plot the following functions in Python:
  - Scatter plot of points: (0,1), (2,3), (5,2), (4,1)
  - Straight Line: $y = mx + b$
  - Sine-wave $y = sin(x)$
  - Polynomial e.g. $y = x^3 + 2$
  - Exponential e.g. $y = e^-2x$
  - Gaussian (Use $\sigma = 0.5$)
  - Choose a function of your own
- Create separate plots for each of the functions, Compute the mean and variance of each function
- Use Wikipedia and Numpy Documentation to search for mathematical formulas and python functions

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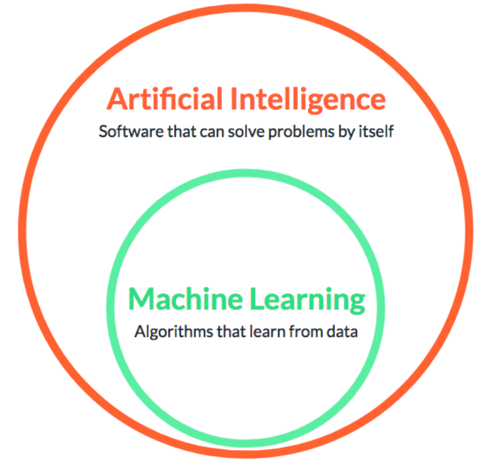
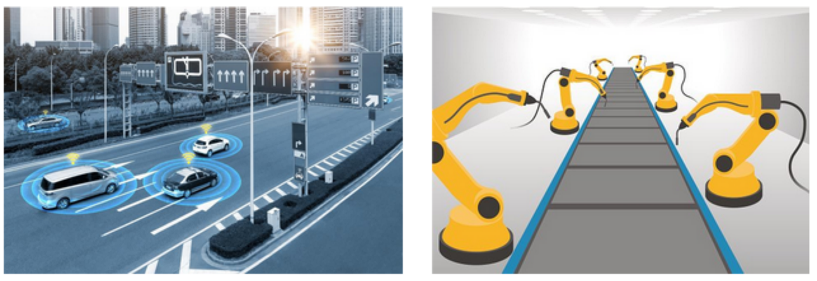
Artificial Intelligence

- Search
- Reasoning and Problem Solving
- Knowledge Representation
- Planning
- Learning
- Perception
- Natural Language Processing
- Motion and Manipulation
- Social and General Intelligence

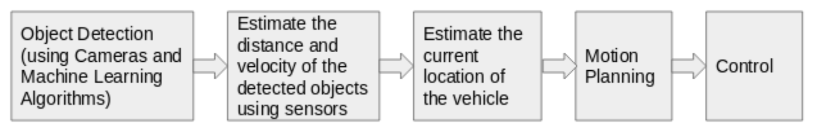
Machine Learning


Artificial Intelligence
Software that can solve problems by itself
Machine Learning
Algorithms that learn from data

Autonomous vs. Automated



Autonomous Example: Driver-less Cars



Object Detection (using Cameras and Machine Learning Algorithms)

Estimate the distance and velocity of the detected objects using sensors

Estimate the current location of the vehicle

Motion Planning

Control

Why is Machine Learning so Prevalent?

- Database mining
- Medical records
- Computational biology
- Engineering
- Recommendation systems
- Understanding the human brain

Why Now?

- Big Data
  - Massive storage. Large data centers
  - Massive connectivity
  - Sources of data from internet and elsewhere
- Computational advances
  - Distributed machines, clusters
  - GPUs and hardware

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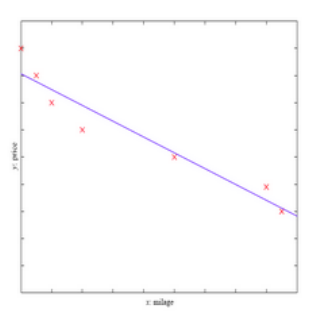
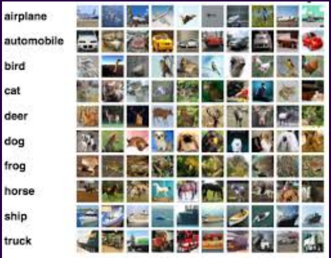
What is Regression?

- Target variable is continuous-valued
- Example
  - Predict y = price of a car
  - From x = mileage, size, horsepower
  - Can use multiple predictors
- Assume some form of mapping
  - Ex: Linear mapping: $y = b + w_1 x$
  - Find parameter b, w_1 from data
- Use target-feature pairings as examples to form model



What is Classification?

- Determine what class a target belongs to based on its features
- Example:
  - Predict y = what type of object is in a photo
  - From x = the pixels of the image
- Learn a model/function from features to target
- Use target-feature pairings as examples to form model



Regression or Classification?

- **Problem 1:** Categorizing credit card applications into those who have good credit, bad credit and those who fall in the gray area.
  - Classification Problem
  - Class Labels: Good credit, Bad credit, Average credit
- **Problem 2:** Determining the sentiment of customer reviews for a product on Amazon.
  - Classification Problem
  - Class Labels: Positive, Negative, Neutral
- **Problem 3:** Predict whether an employee's income is over 100k a year or not.
  - Classification Problem
  - Class Labels: Over 100k, Under 100k

Regression or Classification?

- **Problem 4:** Estimating change in climate.
  - Regression Problem
  - Target Variable: Predicting future temperatures
- **Problem 5:** Identifying hate speech in social media.
  - Classification Problem
  - Class labels: Normal Speech, Hate Speech
- **Problem 6:** Forecasting the energy demand in a region.
  - Regression Problem
  - Target Variable: Predicting the amount of energy needed in the future

Thank You!

- Next Class: ...